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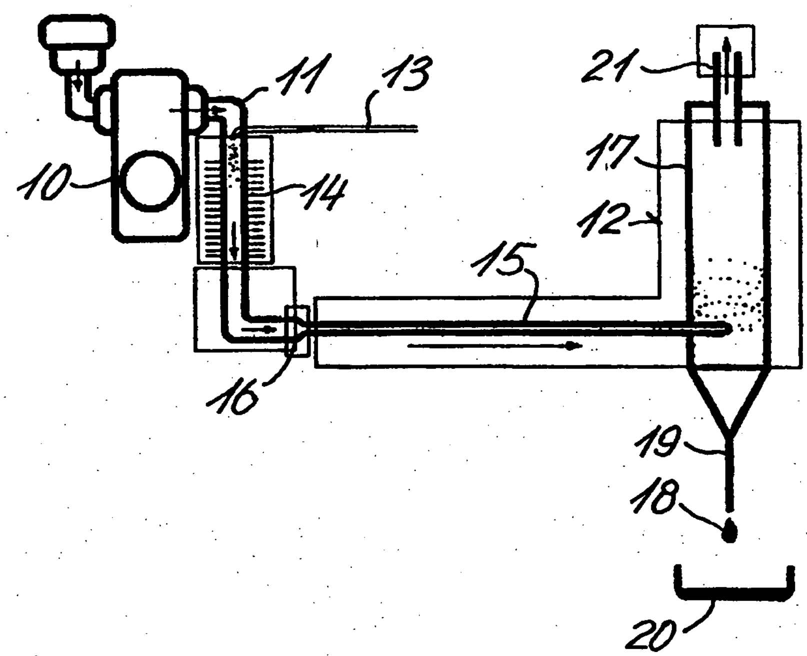
(54) Title: A METHOD AND A DEVICE FOR SEPARATING SOLID PARTICLES FROM A FLOW OF HOT GAS

(57) Abstract

Small solid particles are separated from a flow of gas, such as hot combustion gas from an internal combustion engine (10), especially a diesel engine. As a first step the relative humidity of the gas is increased to a value close to saturation, for example by injecting water or steam in the gas flow by water supply means (13) and/or by external cooling fins (14). Thereafter the flowing gas and the particles therein are cooled substantially adiabaticly to a temperature sufficiently low to cause condensation of water vapour on the surfaces of said solid particles. This may, for example, be obtained by increasing the velocity of the gas flow by reducing the cross-sectional area of the flow passage (15) and/or by directing the gas flow through a turbine. The gas and the particles therein are maintained substantially at such condition for a time sufficient to form water droplets around said solid particles, and finally the water droplets are separated from the combustion gas, for example by means of a filter and/or a cyclone (17).



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A method and a device for separating solid particles from a flow of hot gas.

The present invention relates to a method of separating solid particles from a flow of gas, such as hot combustion gas from an internal combustion engine, especially a diesel engine.

Diesel engines generally have a better fuel economy than gasoline driven internal combustion engines. However, diesel engines are producing exhaust gases containing particulate pollution in the form of very fine soot particles also called smut. While pollution from gasoline driven motors is predominantly in gas phase and can be reduced by catalytic after-burning the particulate smut from diesel engines is much more difficult to remove. After-burning of smut is a slow process due to the limited surface of the particles and removal of the particles by filtration is difficult because the fine particles may pass even very fine filter pores. The fineness of the particles also implicate that they hardly segregate in an even strong field of gravity, such as in a cyclone.

Furthermore, the smut is regarded as a health risk since it contains carcinogenic compounds and is able to penetrate deeply into the lungs when breathed in.

NO-B-162530 discloses a method of neutralising exhaust gases from an internal combustion engine. The exhaust gas or combustion gas is passed through a conduit which includes a converging and diverging Venturi nozzle, and water is supplied to the gorge of the nozzle. Thereafter, the water and possible solid particles and dissolved gases contained therein are separated from the combustion gas.

The present invention provides a method of the type described above by means of which even small solid particles may be efficiently removed from a flow of gas, such as hot combustion gas, by over-saturating the gas with water vapour.

Thus, the present invention provides a method of separating solid particles from a flow of gas, such as hot combustion gas from an internal combustion engine, especially from a diesel engine, said method comprising: increasing the relative

humidity of the gas to a value close to saturation or to its dew point, subsequently substantially adiabaticly cooling by expansion the flowing gas and the particles therein to a temperature sufficiently low to cause condensation of water vapour on the surfaces of said solid particles, maintaining the gas and the particles therein substantially at such condition for a time sufficient to form water droplets around said solid particles, and separating said water droplets from the gas.

When the gas having a temperature close to its dew point and the particles dispersed therein is cooled adiabaticly and not indirectly via the flow passage walls the water vapour tends to condense on the surfaces of the solid particles rather than on the inner passage walls. By maintaining such conditions, which promotes condensation, in a sufficient time interval each particle becomes included in a water droplet, which may be separated from the gas by conventional means.

Said increase in the relative humidity of the gas may be obtained in any suitable manner. As an example the increase may be at least partly obtained by spraying cooling water and/or by injecting steam into the gas flow. Alternatively, said increase of the relative humidity of the gas may at least partly be obtained by passing the gas flow through a conduit section the walls of which are cooled. As an example, exhaust gas from internal combustion engines, such as diesel engines, usually has a dew point about 50° C, and therefore the hot combustion gas exhausted by the engine should as a first step be cooled down to around this temperature prior to the adiabatic cooling.

The adiabatic cooling taking place after having brought the gas into a condition close to saturation of the water vapour therein may also be carried out in various manners. Thus, for example, the adiabatic cooling of the gas may at least partly be obtained by adiabaticly increasing the flow velocity of the gas, whereby enthalpy is converted into kinectic energy and the gas temperature is reduced correspondingly. The temperature drop of the gas and of the particles suspended therein causes condensation of water vapour on the particles which are thereby encapsulated in water. The content of water soluble acids in soot particles accelerates this process.

As water vapour is condensing on the solid particles the heat of condensation liberated rises the temperature of the particle whereby the condensation rate is

reduced. The equilibrium condensation rate is obtained when the heat of condensation being liberated is balanced by the cooling of the particle by the surrounding colder gas. The high velocity gas flow may be obtained in a conduit or passage having a constant or reducing small cross-sectional area, but may, for example, also be maintained in a cyclone.

In embodiment of the method according to the invention water is sprayed into the flow of gas while the gas is flowing through a first passage section, whereafter the gas having a temperature close to its dew point is passed through a second passage section having along the total length thereof a cross-section being substantially smaller than that of the first passage section, whereby the gas flow velocity is increased.

When the necessary high velocity of the gas is obtained in a passage with a small cross-sectional area, the pressure drop by friction may be less acceptable. Therefore, alternatively or additionally the adiabatic cooling of the gas may be obtained by passing the gas flow through a turbine. The energy removed from the gas in the turbine causes the desired temperature reduction.

In order to re-establish the pressure after separation of the water droplets and thereby reduce the total pressure drop of the process, a compressor or gas pump may be located downstream of the turbine so that the gas is compressed from a sub-atmospheric pressure at the downstream end of the turbine to a pressure exceeding atmospheric pressure sufficiently to allow discharge of the gas into the ambient atmosphere. Alternatively, the flowing gas may be compressed by compression means or a pump located upstream of the turbine in order to increase the pressure drop over the turbine.

The compression means or gas pump may be driven by any suitable motor, such as an electric motor. In the preferred embodiment, however, the compressor or pump is driven at least partly by the turbine.

The water droplets and the particles and other polluting matter included therein may be separated from the gas flow by any suitable conventional separating means, such

as filter means and/or by means of a cyclone or a gas scrubber. In this manner a considerable amount of smut and also certain amounts of acid pollutants, such as SOx and NOx, may be separated from the gas as a dirty liquid. Such liquid may be evaporated and the remanent may be dehydrated and disposed off, for example by burning. The evaporated or otherwise cleaned water separated from the flow of gas may be reused.

The present invention also provides a device for separating solid particles from a flow of gas, such as hot combustion gas from an internal combustion engine, said device comprising: means for increasing the relative humidity of the gas to a value close to saturation, means for subsequently substantially adiabaticly cooling by expansion the flowing gas and the particles therein to a temperature sufficiently low to cause over-saturation and thereby almost immediate condensation of water vapour on the surfaces of said solid particles, means for maintaining the gas and the particles therein substantially at such condition for a time sufficient to form water droplets around said solid particles, and means for separating said water droplets from the gas. By means of this device it is possible to efficiently remove even very small solid particles from a hot gas flow in the manner described above.

The invention will now be further described with reference to the drawings, wherein

Fig. 1 diagrammatically illustrates a first embodiment of the device according to the invention,

Fig. 2 diagrammatically illustrates a second embodiment including a gas turbine and a compressor arranged downstream thereof, and

Fig. 3 diagrammatically illustrates a third embodiment of the device according to the invention including a turbine and a compressor arranged upstream thereof.

The drawings illustrate embodiments of a gas cleaning apparatus or device according to the invention for cleaning exhaustion gas from an internal combustion engine, such as a diesel engine 10. The exhaust tube 11 of the diesel engine 10 is connected to a particle separating device or gas cleaning device generally designated by 12. The hot

combustion gas flowing through the exhaust tube 11 is brought into a state in which the exhaust gas or combustion gas contains almost saturated water vapour. This is obtained partly by spraying water into the exhaust tube 11 via a water supply tube 13 and partly by cooling the exhaust tube 11 from outside. Therefore, the exhaust tube 11 is provided with outer cooling ribs or fins 14 and cooling medium, such as air or water, may be caused to flow around the fins 14.

In the embodiment shown in Fig. 1 the combustion gas, which has been cooled to a temperature close to the dew point of the gas, is passed from the downstream end of the exhaust tube 11 into a high velocity tube 15. The inner diameter of the tube 15 is substantially smaller than the inner diameter of the exhaust tube 11, whereby the velocity of the gas flow increases, when the gas passes the junction 16 between the tubes 11 and 15. When the velocity of the gas flow increases the temperature of the gas and of the solid particles dispersed therein drops. Thereby water vapour is caused to condense on the surfaces of the particles so as to form water droplets encapsulating the particles.

The downstream end of the tube 15 opens into a cyclone 17. During passage of the tube 15 and the cyclone 17 the water droplets including the entrained particles have obtained such a size that they may easily be separated from the gas in the cyclone 17. The separated dirty liquid 18 leaves the cyclone through a central lower liquid outlet tube 19 and is collected in a suitable collecting tank or container 20. The cleaned gas is discharged from the cyclone 17 trough a gas discharge tube 21.

In the embodiments shown in Figs. 2 and 3 the high velocity tube 15 has been shortened substantially, and the high velocity gas flow leaving the tube 15 is impinging the vanes of a turbine wheel 22 so as to rotate the turbine wheel. Thereby enthalpy is removed from the gas flow so that a similar effect is obtained within the housing 23 as in the relatively long high velocity tube 15 shown in Fig. 1 with a substantially smaller pressure loss by friction, whereby the efficiency of the diesel engine 10 may be increased.

When the gas has passed the turbine wheel 22 and water droplets have been formed around the solid particles as the gas flows through a housing 23 along a helical path

whereby some of the water droplets may be separated from the gas by centrifugal effect. Thereafter the gas flow passes through a filter 24 arranged in the housing 23. The filter separates further water droplets and the particles therein from the gas, and the dirty liquid 18 separated flows out from the housing 23 through a liquid outlet tube 19. A gas compressor or gas pump 25 may be arranged in the housing 23 opposite to the turbine wheel 22. As shown in Fig. 2 the turbine wheel 22 and the compressor wheel 25 may be connected to opposite ends of a common shaft 26 extending axially through the housing 23, and the compressor may be at least partly driven by the turbine wheel. Thus, the compressor 25 is compressing the cleaned gas having passed the filter 24 and is discharging the gas into the atmosphere via the discharge tube 21 at a pressure slightly exceeding atmospheric pressure.

The embodiment shown in Fig. 3 is similar to that illustrated in Fig. 2. However, in Fig. 3 the compressor wheel 25 is arranged upstream of the turbine wheel 22. Thus, the cooled, humid gas being discharged from the tube 15 is compressed by the compressor or pump 25, whereby the gas temperature is somewhat increased. Therefore, further cooling may be necessary and further water may be introduced into the gas flow upstream of the turbine 22 and immediately downstream of the compressor 25 via a further water supply tube 27. When the cooled, pressurised gas having a temperature close to its dew point passes the turbine wheel 22 the gas temperature drops and in the housing 23 water vapour condenses on the surfaces of the particles entrained by the gas. In Fig. 3 the filter 24 is arranged downstream of the turbine wheel 22 and separated water is discharged through the tube 19. The cleaned gas may be directed through further conventional cooling devices, if desired, to extract more water from the gas for reuse.

It should be understood that various amendments and modifications of the embodiments shown in the drawings and described above could be made within the scope of the present invention. As an example, the cyclone 17 shown in Fig. 1 could be replaced or supplemented by a water separating filter, and the filters 24 shown in Figs. 1 and 2 could be replaced or supplemented by cyclones or other conventional separating means.

Furthermore, the gas being treated by the method and device according to the invention needs not necessarily be hot exhaust gas from internal combustion engines, but may be other kinds of cold or warm gases having small solid particles dispersed therein, such as flue gases or gases from other industrial processes.

Claims

1. A method of separating solid particles from a flow of gas, such as hot combustion gas from an internal combustion engine, said method comprising:

increasing the relative humidity of the gas to a value close to saturation,

subsequently substantially adiabaticly cooling by expansion the flowing gas and the particles therein to a temperature sufficiently low to cause condensation of water vapour on the surfaces of said solid particles,

maintaining the gas and the particles therein substantially at such condition for a time sufficient to form water droplets around said solid particles, and

separating said water droplets from the combustion gas.

2. A method according to claim 1, wherein said increase of the relative humidity of the gas is at least partly obtained by spraying cooling water and/or injecting steam into the hot gas flow.

3. A method according to claim 1 or 2, wherein said increase of the relative humidity of the gas is at least partly obtained by passing the gas flow through a conduit section the walls of which are cooled.

4. A method according to any of the claims 1-3, wherein the adiabatic cooling of the gas is at least partly obtained by adiabaticly increasing the flow velocity of the gas.

5. A method according to claim 4, wherein the high velocity gas flow is maintained in a cyclone.

6. A method according to claim 4 or 5, wherein water is sprayed into the flow of gas while the gas is flowing through a first passage section, whereafter the gas having a temperature close to its dew point is passed through a second passage section having along the total length thereof a cross-section being substantially smaller than that of the first passage section.

7. A method according to any of the claims 1-6, wherein the adiabatic cooling of the gas is at least partly obtained by passing the gas flow through a turbine.

8. A method according to claim 7, wherein the flowing gas freed from water droplets is compressed by compression means located downstream of the turbine.

9. A method according to claim 7, wherein the flowing gas is compressed by compression means located upstream of the turbine.

10. A method according to claim 8 or 9, wherein the compression means are driven by the turbine.

11. A method according to any of the claims 1-10, wherein the water droplets are separated from the gas flow by filter means.

12. A method according to any of the claims 1-10, wherein the water droplets are separated from the gas flow by means of a cyclone.

13. A method according to any of the claims 1-12, wherein water separated from the flow of combustion gas is cleaned and reused.

14. A method according to any of the claims, wherein the gas from which the water droplets have been separated is further cooled in a conduit section the walls of which are cooled so as to condense further water vapour for reuse.

15. A device for separating solid particles from a flow of gas, such as hot combustion gas from an internal combustion engine, said device comprising:

means for increasing the relative humidity of the gas to a value close to saturation,

means for subsequently substantially adiabaticly cooling by expansion the flowing gas and the particles therein to a temperature sufficiently low to cause condensation of water vapour on the surfaces of said solid particles,

means for maintaining the gas and the particles therein substantially at such condition for a time sufficient to form water droplets around said solid particles, and

means for separating said water droplets from the gas.

16. A device according to claim 15, wherein said humidity increasing means comprise means for spraying cooling water and/or injecting steam into the hot gas flow.

17. A device according to claim 15 or 16, wherein said humidity increasing means comprise means for cooling the walls of a conduit section through which the gas flow is passed.

18. A device according to any of the claims 15-17, wherein the adiabatic cooling means comprise means for adiabaticly increasing the flow velocity of the gas and for substantially maintaining the increased velocity.

19. A device according to claim 18, wherein the gas flow velocity increasing and maintaining means comprise a cyclone.

20. A device according to claim 18 or 19, wherein the humidity increasing means comprise a first passage section and means for spraying water into the combustion gas flowing therethrough, the adiabatic cooling means comprising a second flow passage section connected to the downstream end of the first passage section and having along the total length thereof a cross-section being substantially smaller than that of the first passage section.

21. A device according to any of the claims 15-20, wherein the adiabatic gas cooling means comprise a turbine driven by the gas flow.

22. A device according to claim 21, further comprising compression means located downstream of the turbine and the separating means.

23. A device according to claim 21, wherein the compression means are located upstream of the turbine and the separating means.

24. A device according to claim 22 or 23, wherein the compression means are drivingly connected to the turbine.

25. A device according to any of the claims 15-24, wherein said water droplet separating means comprise filter means.

26. A device according to any of the claims 15-25, wherein the water droplet separating means comprise a cyclone.

27. A device according to any of the claims 15-26, further comprising cleaning means for cleaning water separated by the separating means for reuse.

28. A device according to any of the claims 15-27 further comprising moisture condensing means arranged downstream of the separating means for extracting more water from the cleaned gas for reuse.

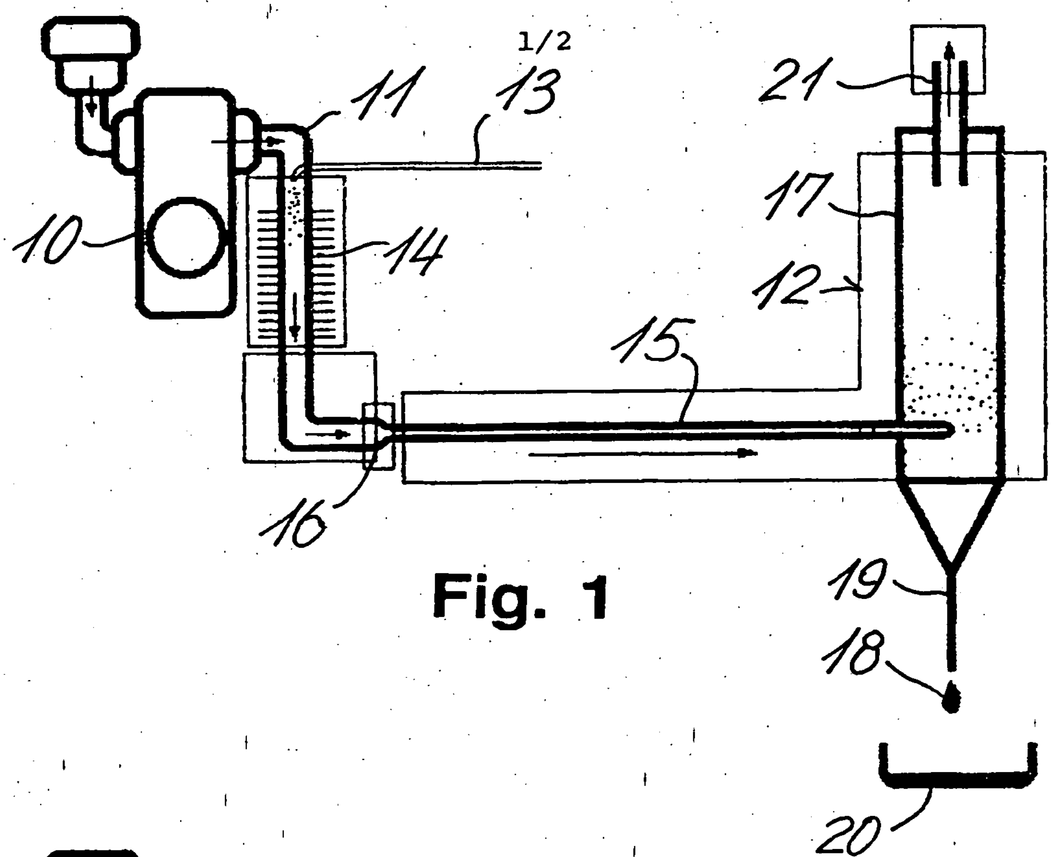

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Fig. 1

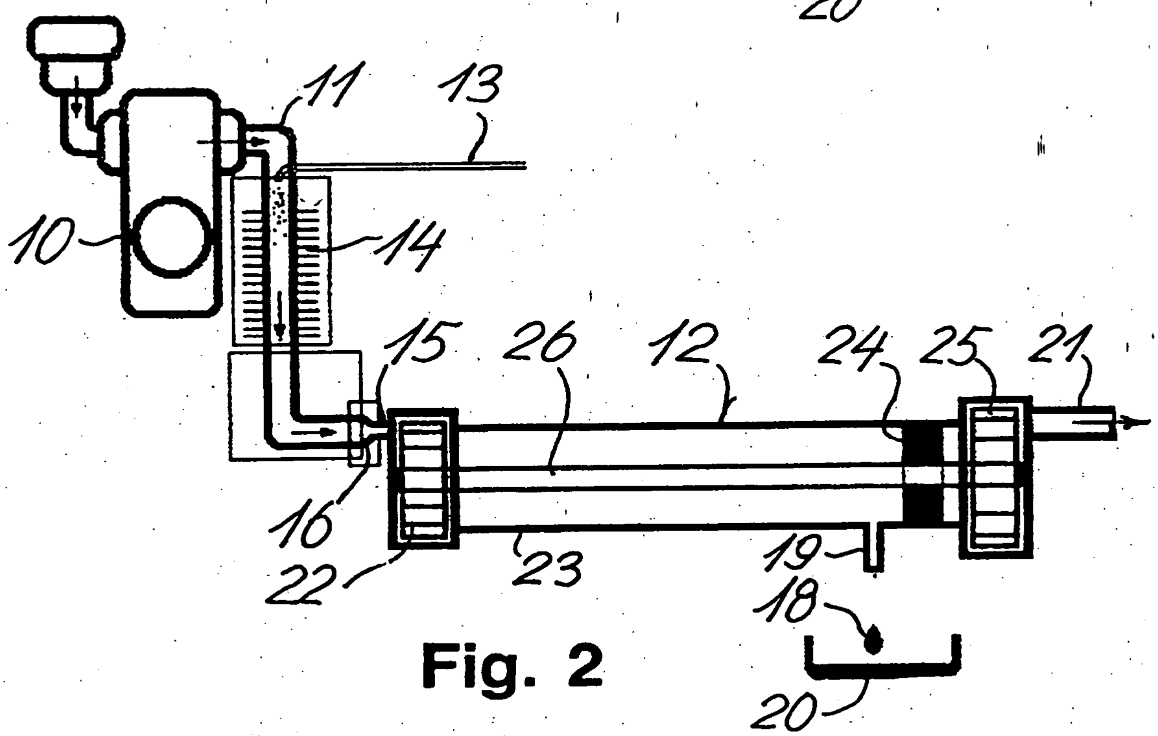

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Fig. 2

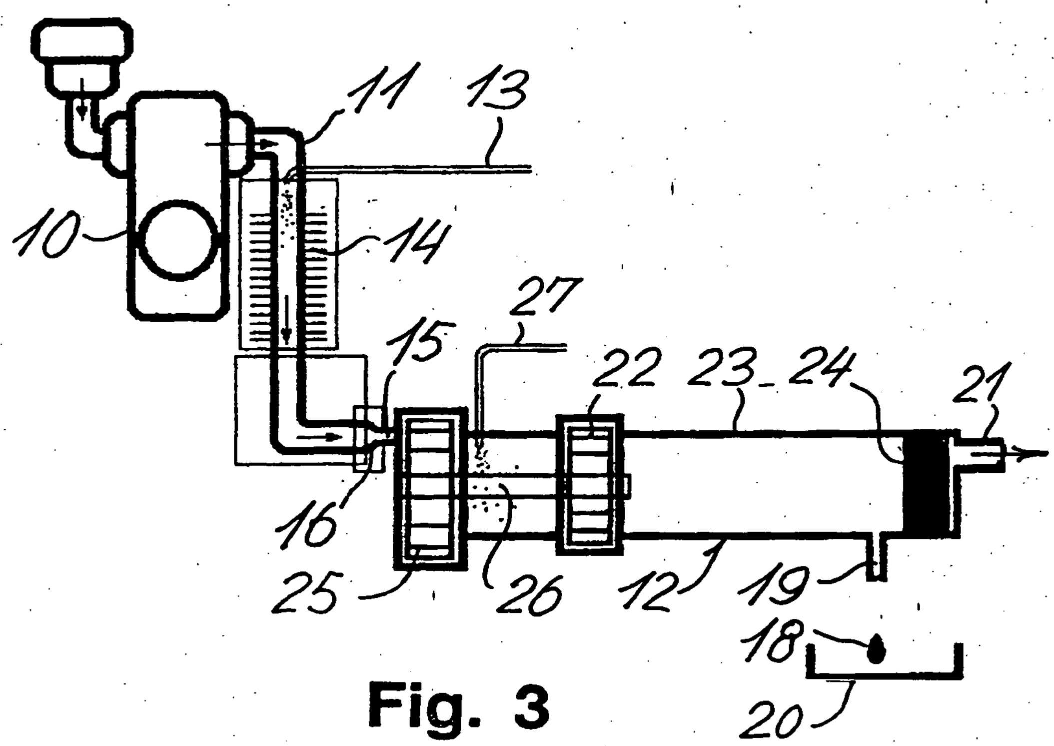

Fig. 3

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 99/00237

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B01D 51/00, B01D 47/00, F01N 3/04
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B01D, F01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
21 Sept 1999	29 -09- 1999
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 99/00237

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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